Tour of GGAO Facilities for Code 600

Background Information

David Carter/Code 453
Frank Lemoine/Code 698
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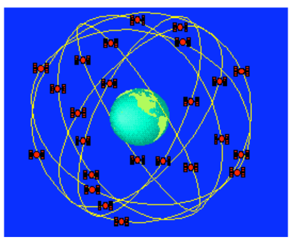
September 25, 2009

Outline

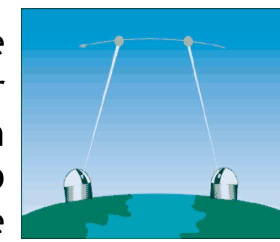
Space Geodesy (1/3)

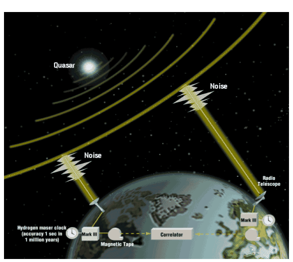
- Geodesy provides a foundation for all Earth observations
- Space geodesy is the use of precise measurements between space objects (e.g., orbiting satellites, quasars) to determine
  - Positions of points on the Earth
  - Position of the Earth's pole
  - Earth's gravity field and geoid



GNSS: Satellites (GPS-U.S., Russia-GLONASS, future EU-Galileo) equipped with precise clocks transmitting messages such as ephemeris, clock offsets, etc. to ground (and spaced-based) receivers to measure station to satellite pseudo-range, phase delay

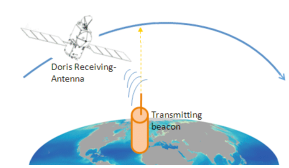
SLR/LLR: Ground-based short-pulse laser transmitting to satellites (or planetary targets) equipped with corner cubes to measure round-trip pulse time-of-flight to satellite





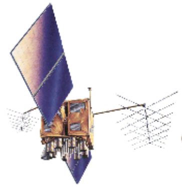
VLBI: Radio telescopes equipped with X/S wideband receivers record signals from quasars to measure difference in signal arrival times

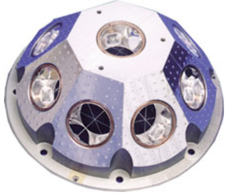
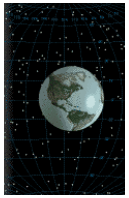
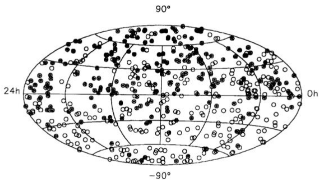
DORIS: Satellites equipped with DORIS receiver and uplink hardware transmit signals to ground beacons to measure Doppler shift on radiofrequency signals

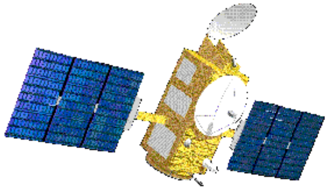


Space Geodesy (2/3)

- Data from space geodesy measurements archive are utilized for direct science observations and geodetic studies, e.g., plate motion, gravity field, earthquake displacements, Earth orientation, atmospheric angular momentum, etc.
- Data also contribute to the determination of the Terrestrial Reference Frame, an accurate set of positions and velocities
  - TRF provides the essential stable coordinate system that allows measurements to be linked over space and time; independent of the technology used to define it
  - Space geodetic networks (GNSS, SLR, VLBI, DORIS) provide the critical infrastructure necessary to develop and maintain the TRF
- Data used for Precise Orbit Determination (POD)
  - SLR and DORIS data used to calculate and verify precise orbits for Earth observation missions (e.g., ERS-1/2, ALOS, Jason-1/2, Envisat, TOPEX, etc.)
  - SLR data and GPS flight receiver data also utilized for POD efforts for other geophysical missions (e.g., GFO-1, CHAMP, GRACE, ICESat, GOCE, etc.)
- Additional products include atmosphere measurements to aid in weather forecasting, etc.
- Provide critical information for accurate deep space navigation



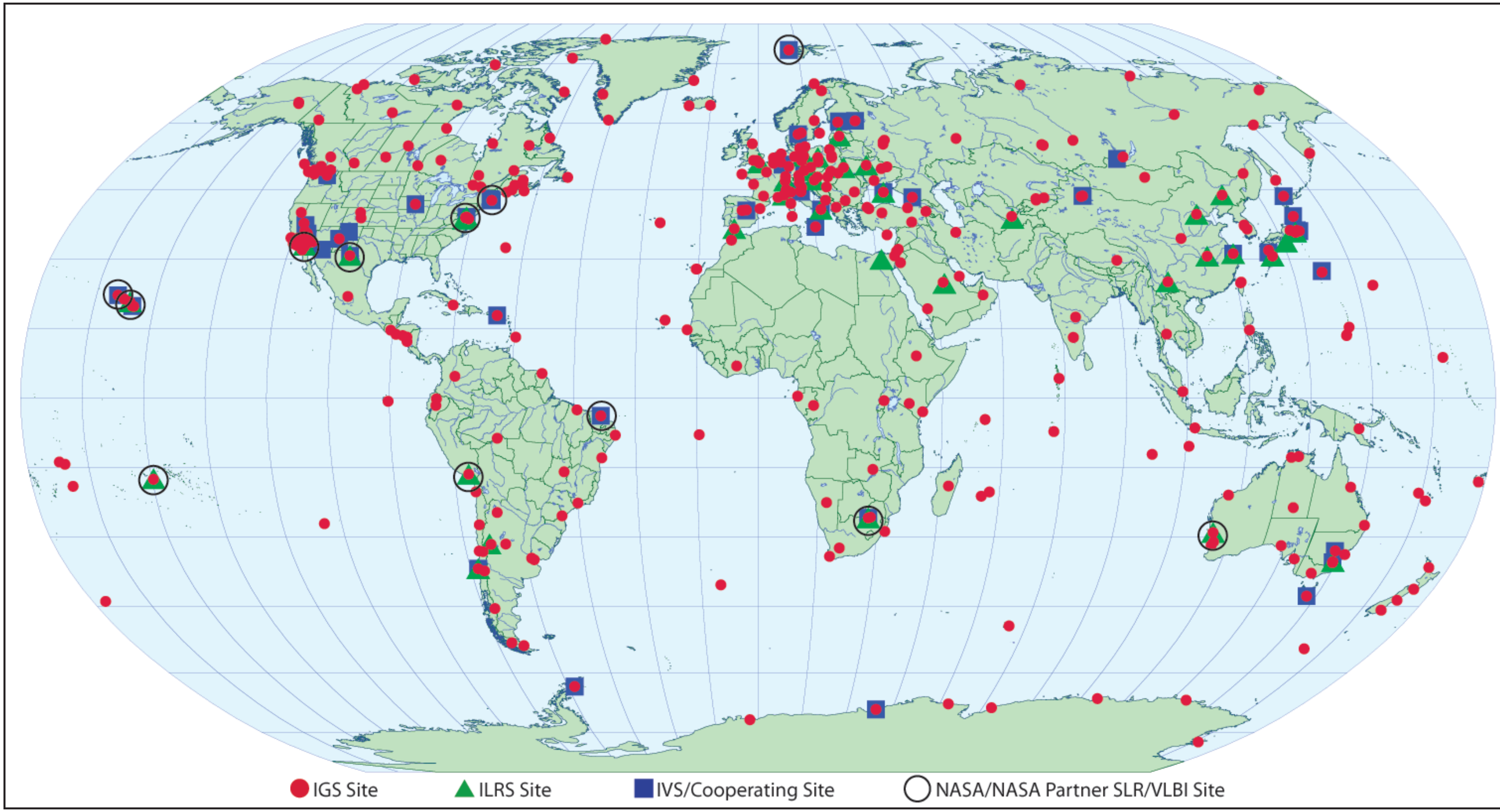








Space Geodesy (3/3)

- Data
  - GNSS: 421 sites tracking GPS, GLONASS
  - Laser Ranging (SLR and LLR): 42 sites tracking 35+ satellites (including the Moon)
  - VLBI: 39 sites
  - DORIS: 57 sites tracking 6 satellites
- Products
  - Precise network station positions (for ITRF)
  - Satellite orbits (for POD)
  - Station and satellite clocks (for timing)
  - Earth rotation parameters
  - Positions of celestial objects (for Celestial Reference Frame, CRF)
  - Atmospheric parameters (Ionosphere Total Electron Content, TEC; Troposphere Zenith Path Delay, ZPD)
  - …
  - Products provided weekly, daily, sub-daily basis

Space Geodesy: Global Networks



Scientific Contributions of Space Geodesy

- Terrestrial Reference Frame (TRF):
  - Station positions and velocities: GNSS, SLR, VLBI, DORIS
  - TRF scale and temporal variations: VLBI, SLR
  - Network densification: GNSS
  - Homogenous network distribution: DORIS
- Celestial Reference Frame: VLBI
- Precise Orbit Determination (POD):
  - Accurate satellite ephemerides: GNSS, SLR, DORIS
  - Calibration/validation for remote sensing missions, instruments: SLR, GNSS
  - Sea level monitoring: GNSS, SLR, DORIS
- Earth Orientation Parameters (EOP):
  - Polar motion and rates: VLBI, SLR, GNSS, DORIS
  - Length-of-day: GNSS, SLR, DORIS
  - UT1-UTC and long-term stability of nutation: VLBI
- Atmosphere:
  - Tropospheric zenith delays: GNSS, VLBI
  - Global maps of ionosphere mean electron content: GNSS, DORIS
  - Limb sounding for global profiles of water vapor: GNSS
- Gravity:
  - Static and time-varying coefficients of the Earth's gravity field: DORIS, SLR
  - Total Earth mass: SLR
  - Temporal variations of network origin with respect to Earth center of mass: SLR
- Timing:
  - Station and satellite clock solutions: GNSS
  - Time and frequency transfer between time laboratories: GNSS
- Fundamental Physics:
  - General relativity and alternative theories: SLR/LLR
  - Light bending, time dilation: VLBI

Who are the Users of the Data?

- International Association of Geodesy (IAG) Services
- NASA and non-NASA Flight Missions
- NSF Polar Programs
- USGS National Earthquake Hazards Reduction Program
- DoD
- Land Surveyors
- NOAA/NGS
- …

IAG Services (1/2)

- Services function as cooperating federations dedicated to a particular space geodesy technique
- Provide data and products on an operational basis to geodesy analysts as well as a broader scientific community
- Examples of a successful model of community management:
  - develop standards
  - self-regulating
  - monitor performance
  - define and deliver products using pre-determined schedules
- 200+ Organizations in 80+ countries
- Successful operation through cooperation of many international organizations who leverage their respective limited resources to all levels of service functionality

IAG Services (2/2)

- NASA actively participates in the services
  - International GNSS Service (IGS)
  - International Laser Ranging Service (ILRS)
  - International VLBI Service (IVS)
  - International DORIS Service (IDS)
  - International Earth Rotation and Reference Frame Service (IERS)
- Services respond to NASA's program needs

NASA's Role Among Global Collaborators

- Networks, through the TRF, provide critical infrastructure to support flight projects
  - This support is assumed by current and future missions to be provided *yet is rarely budgeted or planned*
- NASA leverages its resources by cooperating with international partners
  - NASA supports and coordinates the geodetic services through central offices GSFC (ILRS and IVS) and at JPL (IGS)
  - This NASA coordination is a highly successful international activity endorsed by international organizations such as the IAG
  - NASA's space geodetic data sets are augmented by data contributed by other agencies to the international pool
  - These activities are supported by the Crustal Dynamics Data Information System (CDDIS), a key data center supporting the IGS, ILRS, IVS, IDS, and IERS
  - This results in access to greater and enhanced data sets and products

NASA Needs for Geodetic Networks

- Long term, systematic measurements of the Earth system require the availability of a terrestrial reference frame (TRF) that is stable over decades and independent of the technology used to define it.
- The space geodetic networks provide the *critical infrastructure* necessary to develop and maintain the TRF and the needed terrestrial and space borne technology to support the Earth science goals and missions.
- This infrastructure is composed of the:
  - Physical networks,
  - Technologies that compose them, and
  - Scientific models and model development that define a TRF

Space Geodetic Project Proposal (1/2)

- Joint GSFC/JPL proposal for a Space Geodetic Project (SGP) being prepared for submission to NASA Earth Sciences Division
- Addresses concerns of the Decadal Survey by proposing a NASA contribution to an improved core network of stations incorporating co-located next generation VLBI, SLR, and GNSS components
- Core network essential for NASA Earth Science research objectives and for NASA participation in many international programs
- SGP is proposed to make a significant contribution to the global geodetic measurement systems, to ensure the resulting ITRF will be sufficiently accurate and stable enough to provide accurate estimates of sea level change (critical scientific challenge)
- SGP would be an essential and leading partner in the IAG's Global Geodetic Observing System, GGOS, the international consortium to collect, process, and analyze space geodetic technique data to provide a consistent and stable TRF
- SGP would be designed to meet the needs of Climate Change and GeoHazards research including upcoming missions such as ICESat-II, LIST, GPSRO, Cryosat-2 and DESDynI
- Need for the new stations driven by the rapid deterioration of the present NASA field systems that fall far short of meeting the requirements of the upcoming missions and which have become difficult and costly to maintain.

Space Geodetic Project Proposal (2/2)

- The Space Geodetic Project will enable US-led key science by stabilizing and enhancing the performance of the International Terrestrial Reference Frame and by providing a NASA reference frame product.
- The SGP work elements required to meet cutting-edge scientific mission goals are:
  - Stabilize the network: Revitalize NASA's Space Geodesy ground networks
  - Improve the Reference Frame: Improve the ITRF accuracy and stability to meet anticipated Science Requirements
  - Provide Long-Term Continuity: Long term maintenance of a stable reference frame
  - Successful International Partnering: Assure a diverse, global, redundant source of data and analysis, as well as critical review.
- Proposal requests funds for 18 months to:
  - Complete the prototype next generation systems now underway
  - Develop a plan for the construction of the systems necessary to populate ten stations
  - Select locations and implement these systems as operational stations as NASA’s contribution to the GGOS global network
- Follow-on multi-year phase would implement the plan; also includes support for NASA to work through international partnering to implement the full network and provide long-term continuity in operation and maintenance.

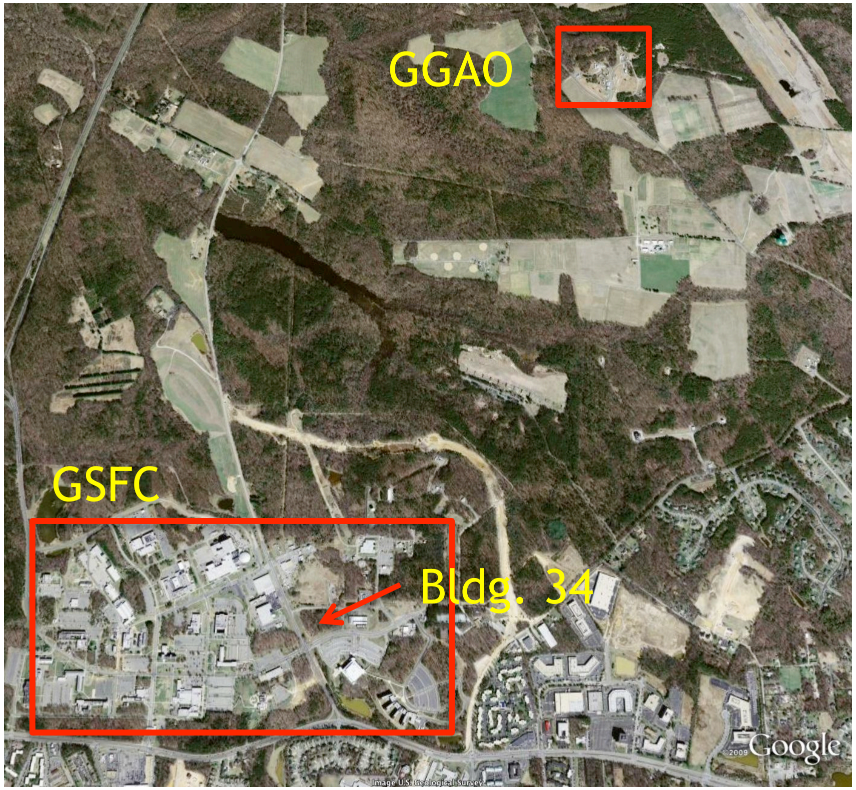
GGAO Overview (1/2)

- Goddard Geophysical and Astronomical Observatory
- GGAO is one of the few sites in the world to have all four geodetic techniques co-located at a single location: Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Global Navigational Satellite System (GNSS), and Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS).
- Code 698 is the Goddard organization responsible for VLBI, GPS and DORIS; SLR operations activity is in Code 453 with the R&D work in Code 694.
- Other activities at GGAO include the X-Ray beam-line (Code 662), low frequency interferometry (Code 695), the Astronomy Club's telescope facility, and many others.
- Contact Jan McGarry/694 (Jan.McGarry@nasa.gov) or Mike Perry/694 (Mike.Perry@Honeywell.com) for more information

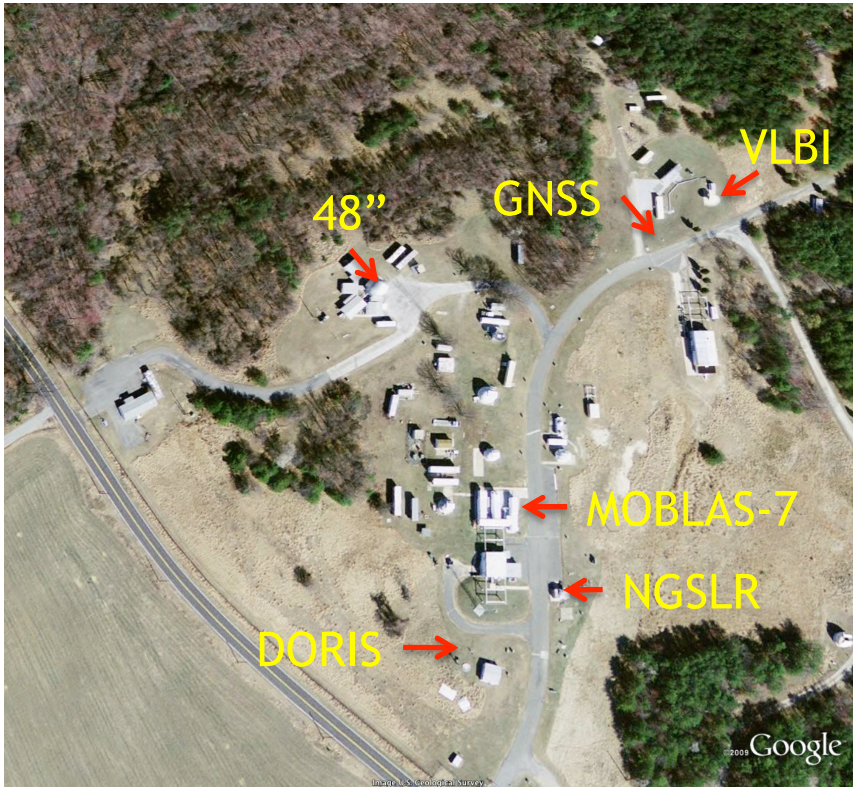
GGAO Overview (2/2)

- GGAO is located 3 miles from Goddard, on Springfield Road, in the middle of the Beltsville Agricultural Research Center.
- *http://cddis.gsfc.nasa.gov/ggao*

Local Area Map



GGAO

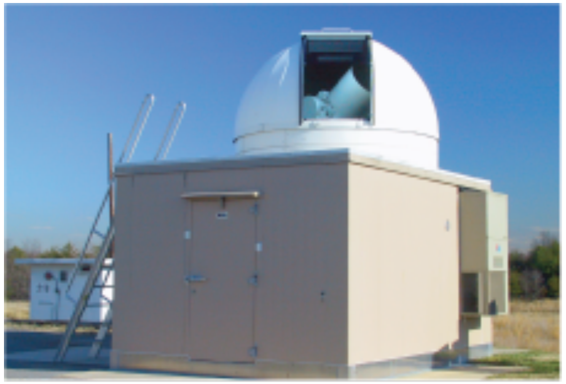


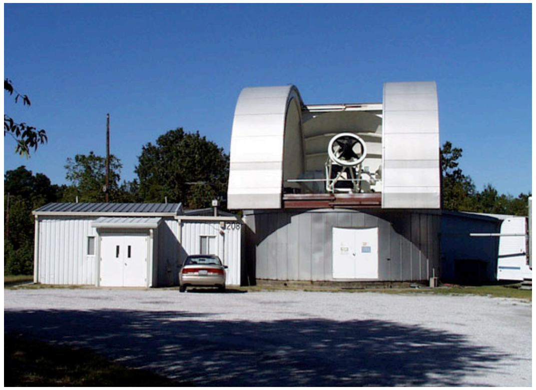
GGAO Facilities and Users

- GGAO is one of only a few sites in world to have all 4 geodetic techniques co-located: SLR, VLBI, GPS, DORIS
  - Operational SLR – MOBLAS-7 (453): David Carter
  - R&D SLR and LRO-LR at NGSLR (694 / 453): McGarry / Zagwodzki / Carter
  - R&D SLR – 1.2 m Telescope (694): Zagwodzki / McGarry
  - VLBI – MV-3 (698): Ma / Rubincam
  - DORIS beacon and GPS Receiver (698): Ma / Rubincam
- Low frequency interferometry (695): Bob MacDowall
- X-Ray beamline (662): Keith Gendreau
- Neutron spectroscopy experiments (690): Ann Parsons
- Primary mirror fabrication through spinning epoxy based compounds (671): Peter Chen
- Search for optical sources of gamma ray bursts (660): Taka Sakamoto
- Development of methods for remote soil analysis (610): Michael Van Steenberg
- 36” telescope: *unclaimed after code 600/900 reorganization*
- Clubs:
  - Explore Scout Post – John Wolfgang
  - Astronomy Club - Kevin Hartnett

SLR at GGAO

- GGAO is home to NASA's SLR activities. Developed at Goddard in the early 1960's as a very accurate tracking technique for satellites carrying retro-reflectors, SLR is now practiced in over 30 countries.
- Two SLR stations at GGAO, MOBLAS-7 and NGSLR, support the laser ranging activities of the International Laser Ranging Service (ILRS), *http://ilrs.gsfc.nasa.gov*; the 1.2M telescope performs R&D activities.
- NGSLR (NASA's Next Generation SLR) is supporting one way (uplink only) ranging to the Lunar Reconnaissance Orbiter (LRO) for the next year to provide more accurate orbital information.
- The 1.2 meter telescope is performing periodic on-orbit calibrations of the Lunar Orbiter Laser Altimeter (LOLA) onboard LRO; three successful on-orbit calibrations have been performed so far.
- <u>Reference & citation</u>:
  Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., The International Laser Ranging Service, *Adv. Space Res.* , 30(2), pp. 135-143, 2002. DOI:10.1016/S0273-1177(02)00277-6.

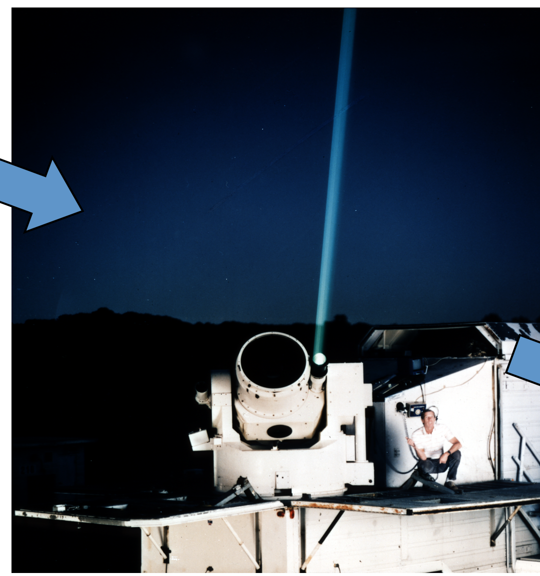




SLR at GGAO: Past, Present, Future

- GGAO is home to NASA's SLR activities. Developed at Goddard in the early 1960's as a very accurate tracking technique for satellites carrying retro-reflectors, SLR is now practiced in over 30 countries.
- Continuous set of GGAO SLR data since 1964

Past: GODLAS

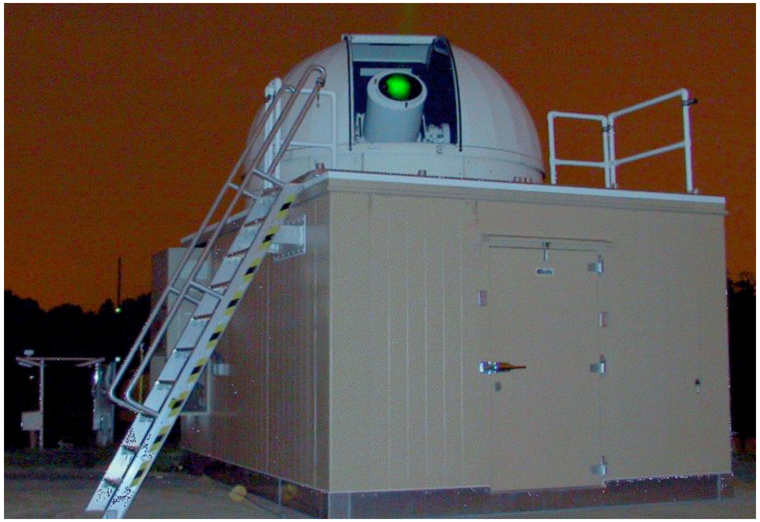


Present: MOBLAS-7

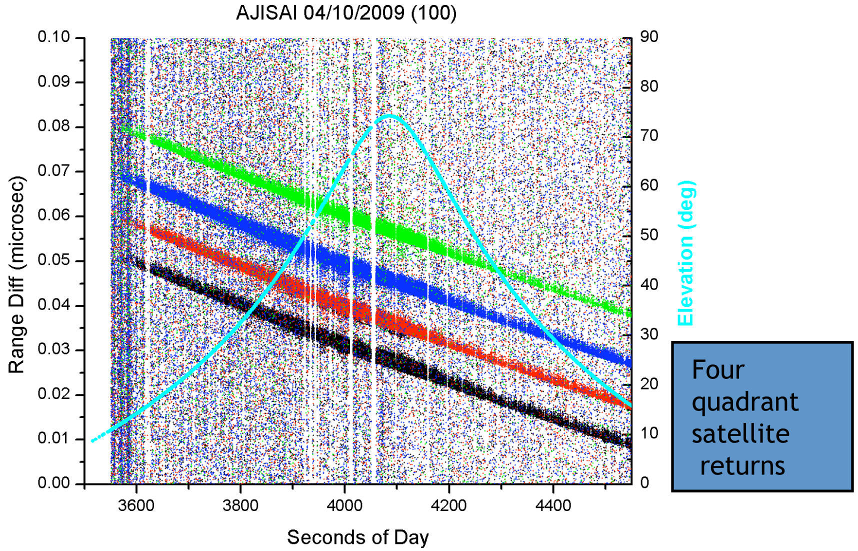
Future: Next Generation Satellite Laser Ranging (NGSLR)

NGSLR Development at GGAO

NASA's Next Generation Satellite Laser Ranging System (NGSLR) is a low energy/high repetition rate singe photon detection laser ranging system capable of tracking cube corner equipped satellites in earth orbit. The concept of NGSLR was developed by J. Degnan (GSFC, retired) in the 1990s. Technical development continues in code 694. The system is currently undergoing final prototype testing at the GGAO and has demonstrated tracking of earth orbit satellites with altitudes from ~ 1000 km to 20000 km.



OMC ranging plot of satellite returns



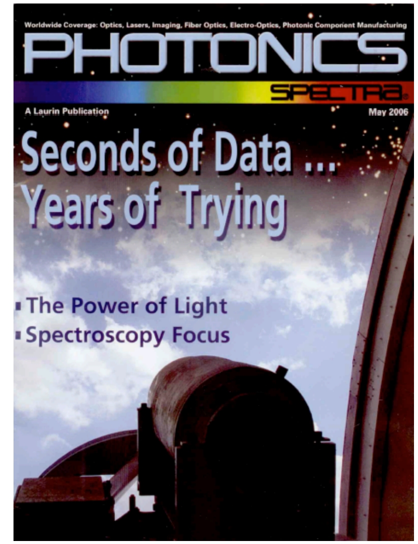
- System Features:
  - 1 to 2 arcsecond pointing/tracking accuracy
  - Track CCR equipped satellites to 20,000 km altitude, 24/7 operation
  - Reduced ocular, chemical, electrical hazards
  - Semi automated tracking features
  - Small, compact, low maintenance, increased reliability
  - Lower operating/replication costs

LRO-LR at GGAO

- Laser Ranging (LR) to LRO from NGSLR operationally 7 days a week.
- LR is 1-way laser uplink. Feedback via LOLA housekeeping data in semi-real-time.
- LR provides data for precision LRO orbit determination (used with S-band tracking).

"Back to the Moon"
LRO Public Tour
(August 1, 2009)

48”(1.2 Meter) Telescope Facility at GGAO



- Multi-user facility built in 1973-74
- Arc-second precision tracking telescope
- Has supported many GSFC experiments including:
  - Mercury Laser Altimeter (MLA) Earthlink 2-Way Laser Ranging
  - MLA onboard MESSENGER at distance of 24 Mkm (Smith, Zuber, Sun, Neumann, Zagwodzki, McGarry): May 2005
  - Mars Orbiter Laser Altimeter (MOLA) Earthlink 1-Way Laser Ranging.
  - MOLA onboard MGS orbiting Mars at ~80 Mkm (Smith, Abshire, Sun, Zuber, Neumann, Zagwodzki, McGarry): Sep 2005
  - LOLA on-orbit calibration, 2-way laser ranging (Smith, Zuber, Zagwodzki, McGarry, Sun, Liiva, Neumann): Aug & Sep 2009

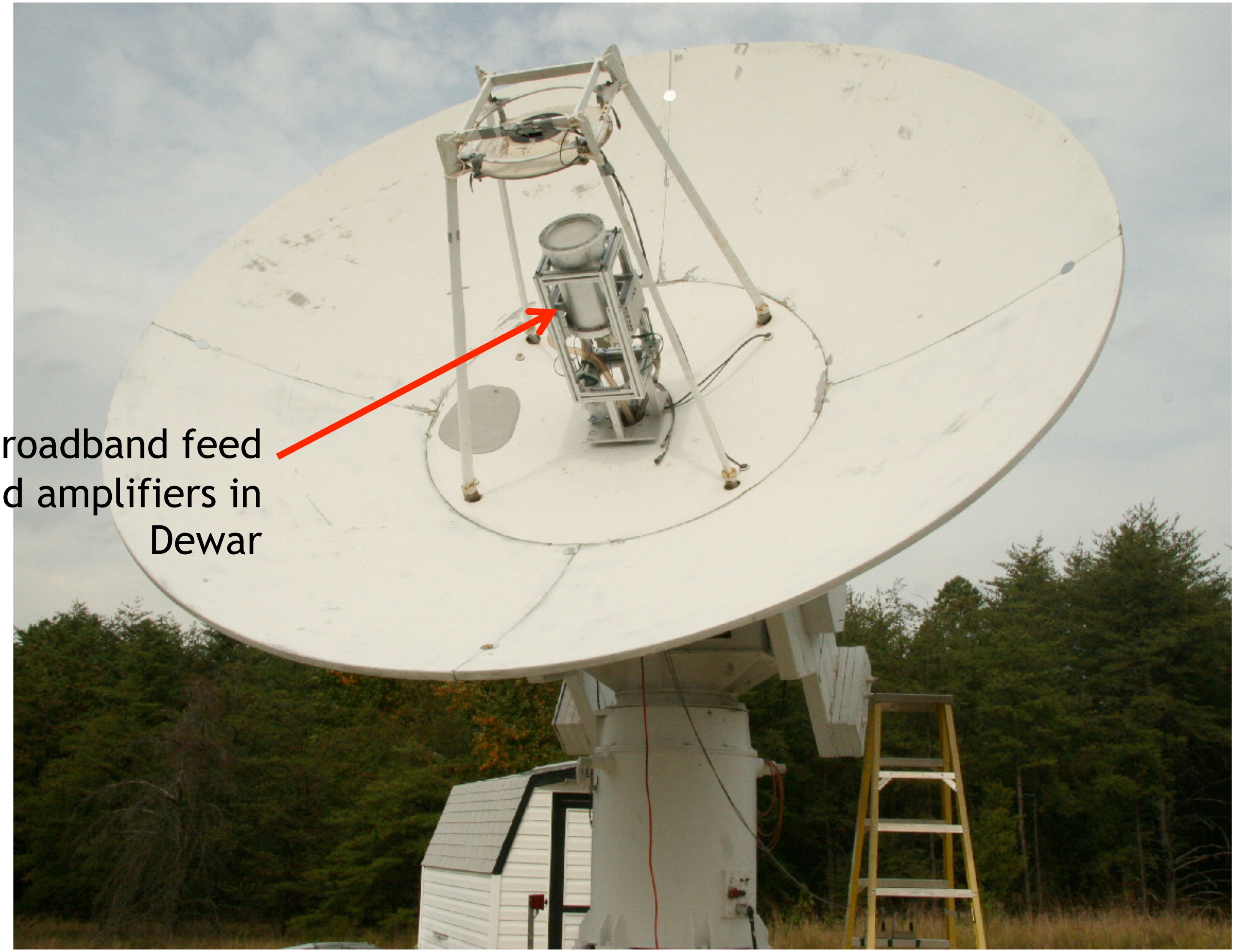
VLBI at GGAO

- MV-3 system was originally a mobile VLBI station supporting the Crustal Dynamics Project that began in 1980.
- Mobile system made measurements in western U.S., Alaska, and Europe.
- Since 1993, MV-3 is a fixed site at GGAO and part of the global network supporting the International VLBI Service for Geodesy and Astrometry (IVS), *http://ivscc.gsfc.nasa.gov*.
- MV-3 now serving as a testbed facility for NASA VLBI R&D, including VLBI 2010 development.
- Reference & Citation:
  W. Schlüter, D. Behrend, The International VLBI Service for Geodesy and Astrometry (IVS): current capabilities and future prospects, *J Geod*, 81(6–8), pp. 379–387, 2007. DOI: 10.1007/s00190-006-0131-z.

VLBI 2010 Demonstration Goals

- Mount cryogenic broadband feeds on antennas at Westford, MA and GGAO.
  - Record 512 MHz from 4 bands between 2 GHz and 14 GHz
  - Dual linear polarizations
- Down convert each band using flexible Up-Down Converter (UDC).
- Separate each band into 32 MHz channels using Digital Backend (DBE).
- Record 2 Gbps on each of 4 Mk5B$^+$ recorders.
- Install fast 12-m Patriot antenna to significantly increase observations.
- Entire VLBI 2010 system is newly designed. Some currently deployed equipment dates from the 1970s.
- VLBI 2010 data expected to be phase delay with much lower uncertainty than current group delay observable.

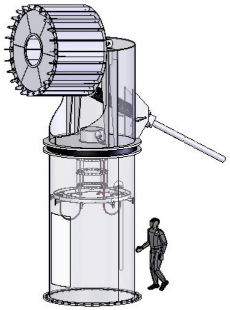
MV-3 5M Antenna

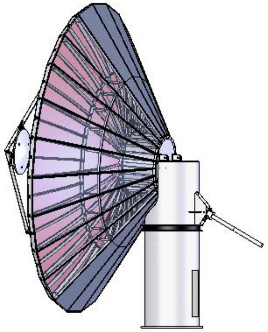


Broadband feed and amplifiers in Dewar

Patriot 12-M VLBI Antenna

- Delivery anticipated December 2009

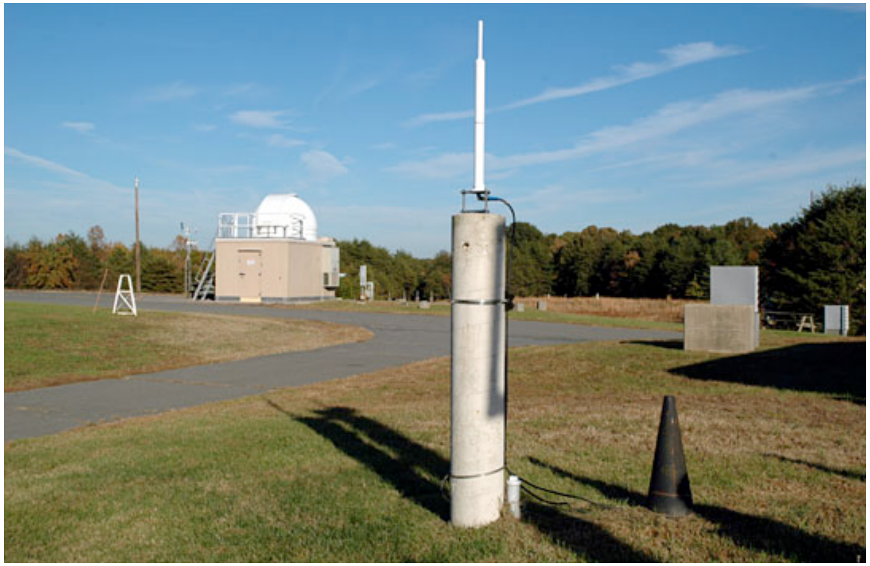




GNSS at GGAO

- Two GNSS receivers (GPS and GPS+GLONASS) share a common antenna at GGAO.
- Both receivers are key contributors to the International GNSS Service (IGS), *http://igscb.jpl.nasa.gov.*
- JPL provides installation and infrastructure support for receiver, antenna, and data download.
- GGAO also used for engineering tests of various GNSS antennas.
- <u>Reference & Citation</u>:
  J.M. Dow, R.E. Neilan, G. Gendt, The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade, *Adv. Space Res*. 36(3), pp. 320-326, 2005. DOI:10.1016/j.asr.2005.05.125

DORIS at GGAO

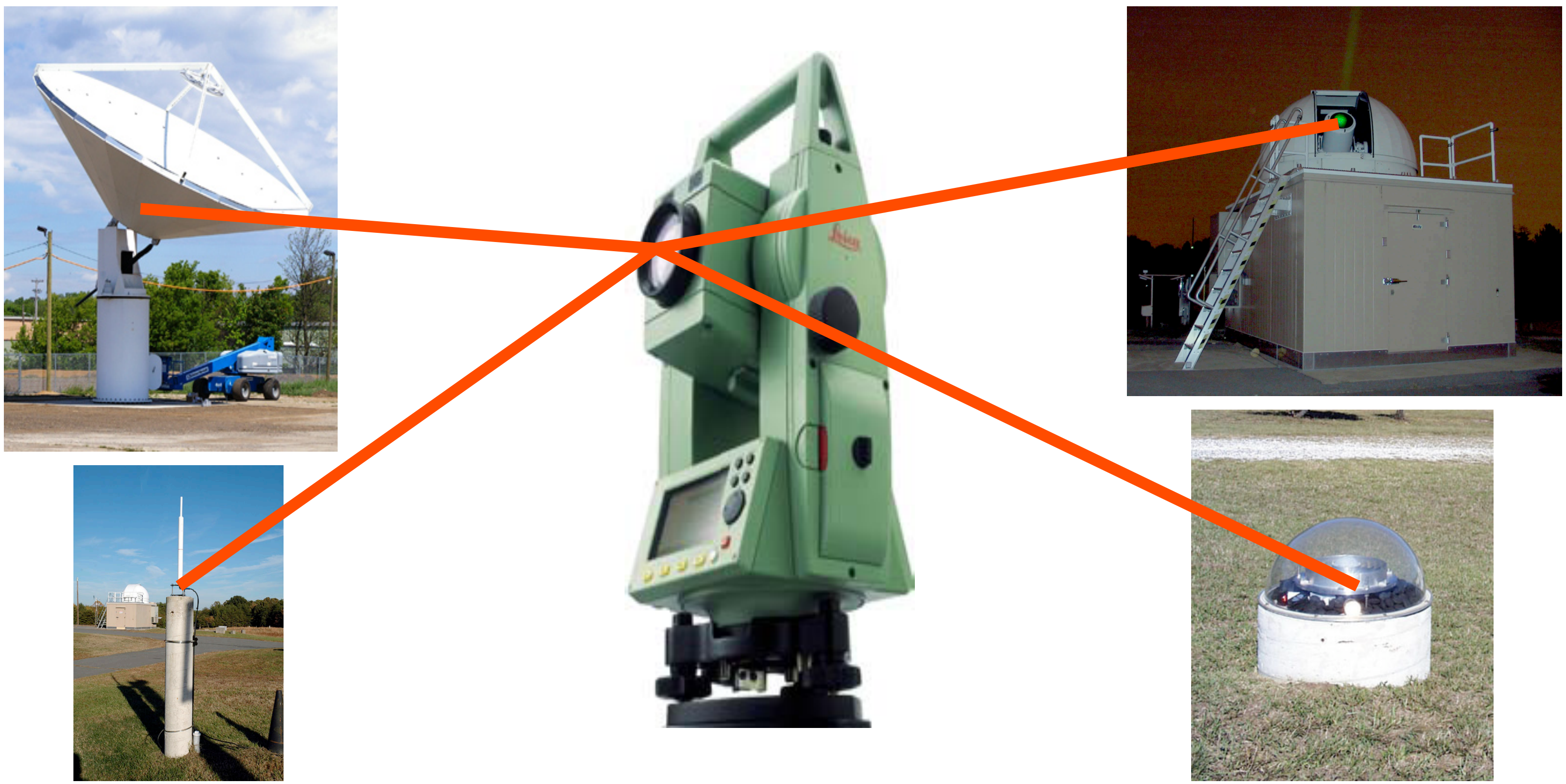


DORIS Global Network

- GGAO DORIS beacon part of a global network of ~57 stations.
- DORIS@GGAO since June 2000
- Beacons emit at 2 Ghz and 400 Mhz; the observable is dual-frequency 1-way Doppler.
- DORIS receivers are located on altimeter (TOPEX/Poseidon, Jason, ENVISAT) and remote sensing (SPOT) satellites; future satellites include: Cryosat-2, Jason-3, SWOT & SENTINEL-3.
- DORIS data are used for Precision Orbit Determination, and contribute to IERS reference frame realizations.
- International DORIS Service URL: *http://ids.cls.fr*
- <u>Reference & Citation</u>: Tavernier, G., Fagard, H., Feissel-Vernier, M., et al., The International DORIS Service: Genesis and early achievements, *J. Geod. 80(8-11)*, pp. 403-417, 2006. DOI: 10.1007/s00190-006-0082-4.

Co-Location Monitoring

- Automated measurement of inter-instrument vectors is an essential aspect of an integrated space geodesy station.
- Measurements provide closure between terrestrial reference frames derived from different space geodesy techniques.
- Tests of technologies and currently available systems underway at GGAO.



GGAO Issues and Concerns

- **No dedicated funding for GGAO facility**
  - Collect minimal amount from users to pay for on-site FOM
- **Center infra-structure support**
  - Slow erosion of what the center will cover (and has money for)
  - Many buildings at GGAO are in need of repairs that no one has money to perform; the buildings' appearance is an embarrassment when giving public tours (such as August 1st "Back to the Moon" LRO tour)
  - *We are doing state of the art ranging at the 1.2 meter telescope but we have doors that are so rusted they won't open*